EVALUATION OF PHYSICO-MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITES MANUFACTURED FROM THE POD OF *Delonix regia* AND WASTE LYLON

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Abstract

This study evaluated the effects of production variables on the physical and mechanical properties of Wood Plastic Composites produced from the pod of Delonixregia and pure water nylon. The boards were produced at three levels of mixing ratio. (MR 1.1), (MR 1.2) and (MR 1.2.5) of wood fiber to pure water nylon and two levels of board density, BD1 (100kg/m^3) and BD2 (1100kg/m^3). The materials were fed into the Extruder machine at the required levels of production variable, the temperatures of the extruder were controlled at 170^{0}C, 180^{0}C, 185^{0}C and 190^{0}C for zones 1, 2, 3 and 4 respectively while the temperature of the extruder die was held at 200^{0}C. The screw speed was varied between 150 revolutions per minutes and the pressure from 33 to 47 bars. The extruded strand passed through a water bath and was subsequently pelletized and ran into a mold of 300mmx180mmx6.4 and hot pressed for thirty (30) minutes. The board produced was conditioned and test samples of 128mmmmX12mm x 6.4mm were cut for evaluating the water absorption, thickness swelling, modulus of elasticity and modulus of rupture. The value obtained for water absorption for 24 hours ranges from 1.22±0.241% to 2.03±0.163 % and that of Thickness Swelling ranges from 0.05±0.014 to 0.14±0.032%, Water Absorption for 48 hours ranges from 1.24±0.234 to 2.08±0.184% and that of Thickness swelling ranges from 0.05±0.017 to 0.17±0.043%. The results obtained showed that rate of water absorption of the boards produced increased from 24 hours of soaking through 48 hours. Also, an increase in mixing ratio resulted in decrease water absorption. The mean value for MOE ranges from 640.60±64.890 to 1204.63±215.847N/mm^2 while that of MOR ranges from 33.48±10.238 to

42.56±14.132N/mm^2.This result shows that the mechanical properties increases as the plastic content in the mixture increases.

Key words: Physico - Mechanical Properties, Wood Plastic Composites, Pod of *Delonix regia*.

Introduction

The high rate of deforestation and forest degradation due to the increase in demand for wood-based panel products, have raised an important issues regarding the sustained supply of raw materials to the wood-based industry. Therefore, to overcome this problem, researchers, both in industry and academia, are looking for new sources of lingo-cellulosic materials. Alternative fibres such as agricultural residues, recycled paper and non-woody fibres could play a major role in providing the equilibrium between supply and demand for the manufacturing of wood base panel products such as particle board, fibre board and wood plastic composites (Nemli and Aydin 2007). Composite is the combination of a matrix and a reinforcement, which when combined gives properties superior to those of the individual components (Ashori and Nourbakhsh, 2009). Wood plastic composite is therefore a combination of wood and plastic with the plastic as the matrix and the wood as the reinforcement.

Wood plastic composite (WPC) can be made from virgin materials as well as recycled ones. In Nigeria, plastic waste is enormous and its disposal has always been a challenge. In using recycled plastic for WPC's, the advantages are that; the raw materials are readily available, it controls the plastic waste hazard and also save some virgin and natural products. Substantial increase in human population and the consequential strain on natural resources such as forests and the associated harmful results as well as the plastic menace challenging the nation are some of the challenges that make the study of WPC important. The use of plastics in the world and developing countries specifically is increasing daily due to the fact that plastic is cheap, light, flexible, easy to shape and recyclable (Wang *et al*. 2010). These properties and others make plastics find their way into the production of many products, from engineering, construction, domestic, electronics and many more products (Ziaei *et al*., 2011, Olayanu et al., 2022a). Some plastic products are made to last longer after the end of life, while others are disposable. Disposable plastics are usually cheap and as such discarded after a first or second use. Large volumes of waste plastic products are discarded daily in developing countries and are found in drainages, on the streets and market places if not collected. At the dump site and landfill sites, plastic waste cover a large space compared to the other waste products and their non-biodegradable nature worsen the situation. The three R's (that is Reduce, Reuse or Recycle) have usually been used to manage the plastic waste problem. In developing countries, only a small amount of the plastic waste generated daily is reused or recycled with the larger percentage going into landfill.

WPCs can be used in several applications such as profiles, sheathing, Decking, Floor tiles, Window trim, automotive parts, doors etc. Natural fibres such as wood are considered environmentally friendly and sustainable due to their renewability and biodegradability (Oyelere et al., 2019, Majekobaje et al., 2022). The WPC's industries are growing very fast, the increasing environmental awareness and lower cost of materials seems to be the driving force. Several research works have been done into the improvement and performance of WPCs and others are still on-going. This work looked at the effects of *Delonix regia* pods on the mechanical and physical properties of WPC's. *Delonix regia* grows in the tropical and sub-tropical region as ornamental tree, the seeds of *Delonix regia*is used for many important things among which is the production of oil, but it had been noticed that once the seeds have been extracted from the pods the pods are thrown away because people believe it is of no use. This research work examines the potential production of WPCs from recycled pure water nylon and *Delonix regia* pods.

Materials and Method

The materials used for this project include: Pure water nylon, *Delonix regia* pods, Universal testing machine, engine oil for easy de-moulding of the board, forming mold, sieve mesh for screening. *Delonix regia* pods were sourced from the Forestry Research Institute Malaysia (FRIM). The pods were sun-dried for three (3) days; all the floppy materials in it that can cause deformation of the boards were removed. The pods were cut into smaller pieces before milled into fine particles using milling machine at FRIM feed mills, where it was milled into fine particles using milling machine. Also, the pure water nylon was milled into granulated particles. The material (*Delonix regia* pods) was sieved in other to obtain uniform size particles and to remove any solid waste. The larger particles were disposed off while the smaller particles were used in production. The shredded pure water nylon was also screened.

Board formation (Extrusion)

The wood flour (D*elonix regia* pod) was compounded with granulated pure water nylon in a co-rotated twin-screw extruder. The temperatures of the extruder were controlled at 170^0C, 180^0C, 185^0C and 190^0C for zones 1, 2, 3 and 4 respectively while the temperature of the extruder die was held at 200^0C. The screw speed was varied between 150 revolutions per minutes and the pressure from 33 to 47 bars. The wood flour and the pure water nylon were premixed before being fed into the first zone of the extruder. The extruded strand passed through a water bath and was subsequently pelletized i.e. the extruded strand was cut into smaller pieces for easy hot pressing.

Properties Determination

Specimen size of 128 mm x 12 mm x 6.4 mm in each WPC produced was measured and subjected into water immersion treatment in cold water for 24 and 48 hours respectively. This test was carried out to examine the behaviour of the WPC samples to water exposure. Thickness Swelling (TS) was obtained by measuring the initial thickness of the board using a veneer calliper before soaking the boards in water. After the initial reading has been taken and recorded, the boards were soaked in water for 24 and 48 hours respectively. The Thickness Swelling is expressed as the percentage of increase in thickness of the board over the initial thickness.

The formula is given below:

$$TS(\%) = \frac{T_2 - T_1}{T_1} \; x \; 100$$

Where,

T_1 = Initial thickness

T_2 = Final thickness

Water Absorption (WA)

The board samples for water absorption were measured using the weighing balance for the initial weight before soaking it in water, after which the readings were taken for 24 and 48 hours respectively. Water absorption is expressed as increase in weight per unit weight of the board as shown in the equation below:

$$WA(\%) = \frac{W_2 - W_1}{W_1} \; x \; 100$$

Where,

W_1 = Initial weight before soaking

W_2 = Final weight after soaking

Mechanical test properties

For the Mechanical test the boards were cut into 128mm ×12mm ×6.4mm to test for the Modulus of Rupture and Modulus of Elasticity.

Modulus of Rupture (MOR)

The modulus of rupture is the maximum carrying capacity of a wooden member. The modulus of rupture was determined using a universal testing machine. The wood specimens were cut into 128mm x 12mm x 6.4mm and was placed in the universal testing machine supported by two rollers at both ends and loaded at the middle of the span until failure occur (Olayanu et al., 2022b).

Formula for calculating MOR is given below:

$$MOR\ (N/mm^2) = \frac{3PL}{2bd^2}$$

Where,

MOR = modulus of rupture

P = load needed for failure

L = span of the material between support (length)

b = width of the material

d = thickness of the material

Modulus of Elasticity (MOE)

MOE is the measure of the stiffness properties of the board which was determined by conducting a bending test on the board. The equation for MOE is given below

$$MOE\ (N/mm^2) = \frac{3PL}{4bd^3D}$$

MOE = modulus of elasticity

P = load needed for failure

L = span of the material between support (length)

b = width of the material

d = thickness of the material

D = the displacement at beam centre at proportional load

Experimental design

The statistical model used for this research work was 2×3 factorial experiment in Completely Randomized Design (CRD), with 2 levels of board density and 3 levels of mixing ratio, at wood/plastic mixing ratios.

Table 1: Factorial experimental design

	MR1 (1:1)	MR2 (1:2)	MR3 (1:3)
BD1 (1000kg/m^3)	BD1MR1	BD1MR2	BD1MR3
BD2 (1100kg/m^3)	BD2MR1	BD2MR2	BD2MR3

Where:

BD = Board Density

MR = Mixing Ratio

Data Analysis

2 x 3 factorial experiments in completely randomized design (CRD) was analysed using Microsoft Excel and Statistical Package for Social Science (SPSS) to investigate the influence of the pod of *Delonix regia* and recycled pure water nylon at wood/plastic mixing ratios (1:1, 1:2 and 1:2.5) and board density of 1000kg/m^3 and 1100kg/m^3 on the physical and mechanical properties of the composites.

Result and Discussion

Physical properties of Wood Plastic Composites

The physical properties of the composites produced were determined by soaking it in water for the period of 24 hours and 48 hours respectively, Fig 1 and 2 below shows the mean values of physical properties carried out on WPCs produced from *Delonix regia* pods and recycled pure water nylon. The value obtained for water absorption for 24 hours ranges from 1.22±0.241to 2.03±0.163 % and that of Thickness Swelling ranges from 0.05±0.014 to 0.14±0.032%, Water Absorption for 48 hours ranges from 1.24±0.234 to 2.08±0.184% and that of Thickness swelling ranges from 0.05±0.017 to 0.17±0.043%. WPCs made from different mixing ratio and density reacted differently to moisture at different wood/plastic ratio. The physical properties varied significantly among the wood/plastic ratio such that values decreased as plastic content in the formulation increases.

The water absorption reduces as the density increases, the density reflects the quantity of materials in the board produced and this aided effective compaction of the board because there is more fibre to fibre bond. Increase in mixing ratio cause decrease in water absorption; this is because there is more enveloping of the particles of *Delonix regia* pods by the pure water nylon. At a mixing ratio of 1:1 of (*Delonix regia* pods particles/ pure water nylon), higher rate of water absorption was observed because of the decrease in pure water nylon content, this observation agree with the findings of (Aina *et al*., 2016) which revealed that increase in plastic content caused improvement in the physical properties of the boards and also increase in plastic content prevent moisture intake. The results of ANOVA in the (Table 2 and 4), shows that there are significant different in all the factors at ($P \leq 0.05$) for Thickness Swelling and (6 and 8) Water Absorption, the follow up test were carried out using Duncan Multiple Range Test (DMRT) to determine the best mixing ratio for both thickness swelling and water absorption and the results were presented in table (3 and 5) and (7 and 9) below.

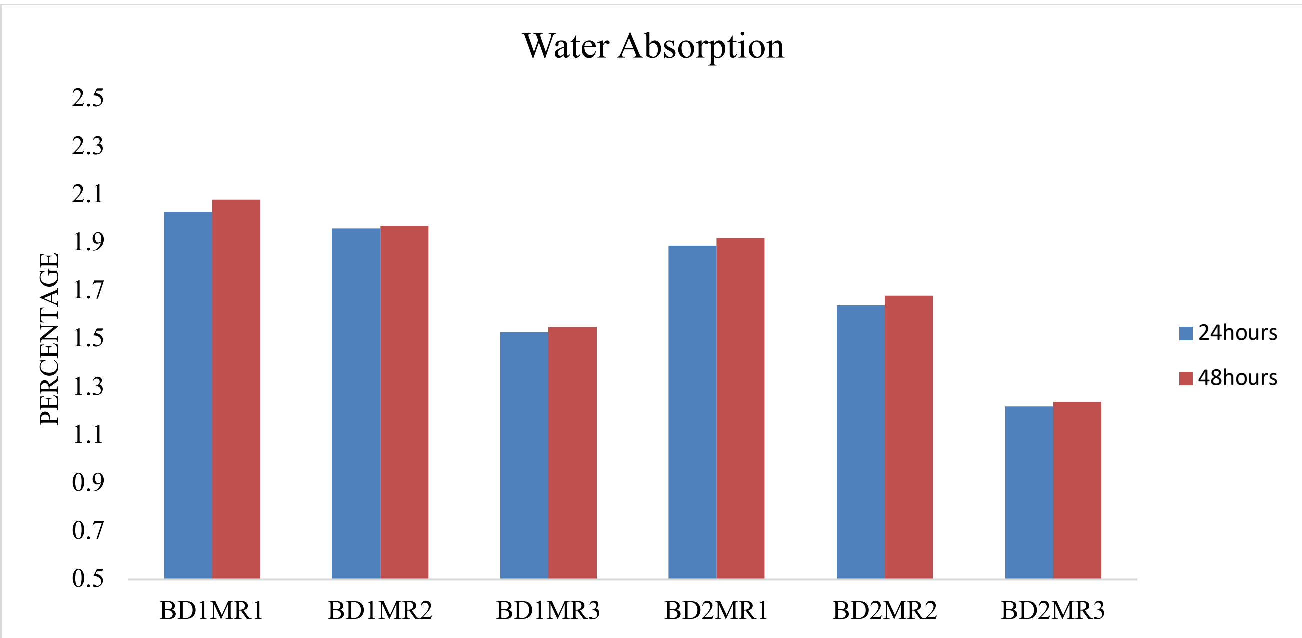

Figure 1: Effect of mixing ratio and density on Water Absorption

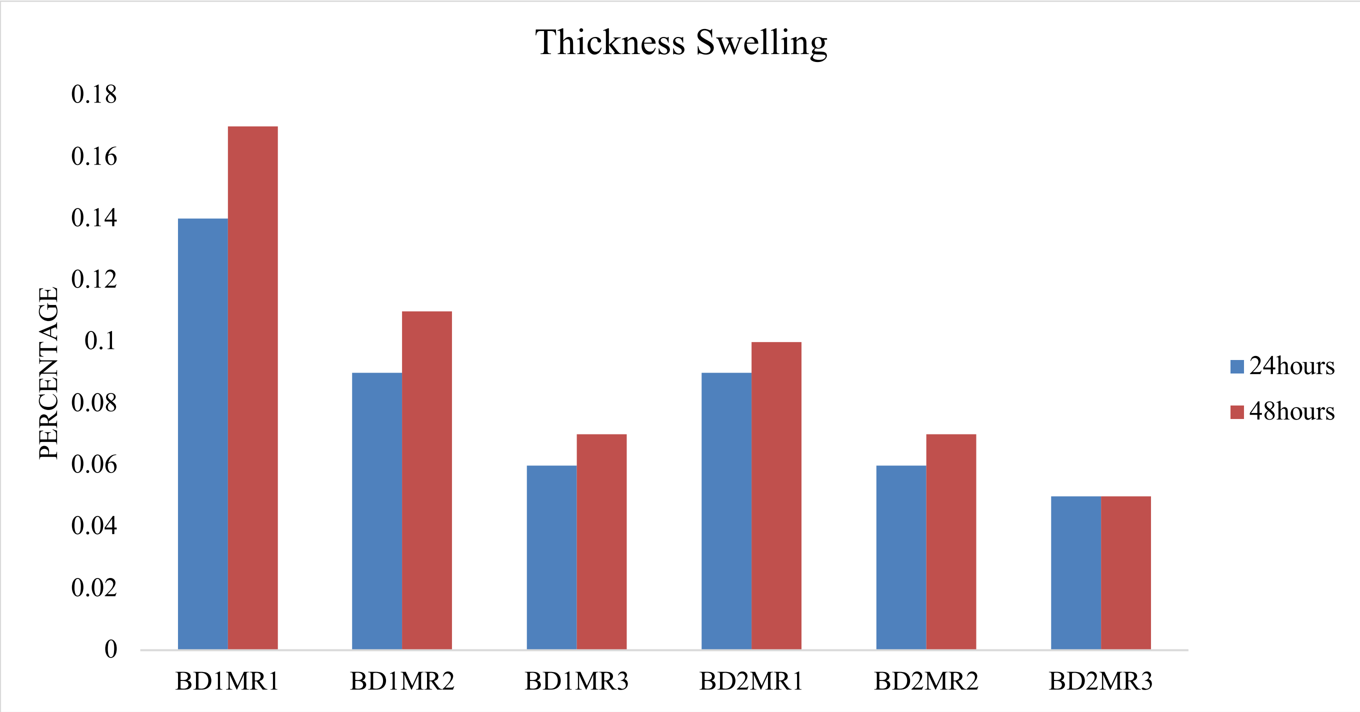

Figure: 2 Effect of Mixing ratio and Density on Thickness Swelling

Table 2: Analysis of Variance for TS, WA, MOE and MOR

SV	DF	SS	MS	Fcal
TS 24hrs Board Density	1	0.003	0.003	72.200*
Mixing Ratio	2	0.007	0.004	88.200*
Board Density * Mixing Ratio	2	0.001	0.000	9.800*
Error	6	0.000	$4.167x10^{-5}$	
Total	11	0.011		
TS 48hrs Board Density	1	0.005	0.005	69.444*
Mixing Ratio	2	0.011	0.005	71.444*
Board Density * Mixing Ratio	2	0.002	0.001	10.111*
Error	6	0.000	$7.500x10^{-5}$	
Total	11	0.018		
WA 24hrs Board Density	1	0.198	0.198	289.220*
Mixing Ratio	2	0.725	0.362	530.159*
Board Density * Mixing Ratio	2	0.022	0.011	16.329*
Error	6	0.004	0.001	
Total	11	0.949		
WA 48hrs Board Density	1	0.221	0.221	450.322*
Mixing Ratio	2	0.731	0.366	743.542*
Board Density * Mixing Ratio	2	0.008	0.004	7.847*
Error	6	0.003	0.000	
Total	11	0.963		
MOE Board Density	1	79293.52	79293.52	1380.251*
Mixing Ratio	2	284473.70	142236.85	2475.896*
Board Density * Mixing Ratio	2	47334.60	23667.30	411.973*
Error	6	344.69	57.45	
Total	11	411446.50		

MOR	Board Density	1	4.514	4.514	36.705*
	Mixing Ratio	2	33.175	16.587	134.875*
	Board Density * Mixing Ratio	2	1.809	0.905	7.356*
	Error	6	0.738	0.123	
	Total	11	40.236		

Mechanical properties of Wood Plastic Composites

The mean values for the Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) are presented in the figure 3 and 4. MOE ranges from 640.60±64.890 to 1204.63±215.847N/mm^2 while MOR ranges from 33.48±10.238 to 42.56±14.132 N/mm^2.

The value of MOE increases with increase in the density and mixing ratio, this is in agreement with previous findings of (Adhikary, 2008 and Williams, 2003) that as the density increases modulus of the WPC increased. The high value of MOE recorded could be as a result of increase in the level of the pure water nylon and density, thus, there is less air space in the board which could act as a point of failure during loading. The total enveloping of the fibres with the pure water nylon increases the stiff nature of the board produced thereby increasing the amount of the force that the board can accommodate before failure. The density of the boards also had effect on the MOR, while the density increases, the MOR increases. As wood to plastic content increases, the Modulus of Elasticity increases; this is in agreement with previous findings of (Aina *et al.*, 2013, Majekobaje 2018, Danyadi *et al.*, 2007, Rodrigo *et al.*, 2001, and Kazayawoko *et al.*, 1997). The observation in strength properties of the boards might be as a result of more molten plastic been occupied by the fillers in the matrix; this increases the inter-particle bonding relationship between the wood powder and plastic content in the matrix. The board produced at BD2 (1100kg/m^3), and MR (1.2.5) of wood/plastic has the strongest board. In the results of ANOVA (Table 13 and 15), shows that there are significant different in all the factors at ($P \leq 0.05$) for Modulus of Elasticity and Modulus of Rupture, the follow up test were carried out using Duncan Multiple Range Test to determine the best mixing ratio for both MOE and MOR and the results were presented in table 14 and 16 below.

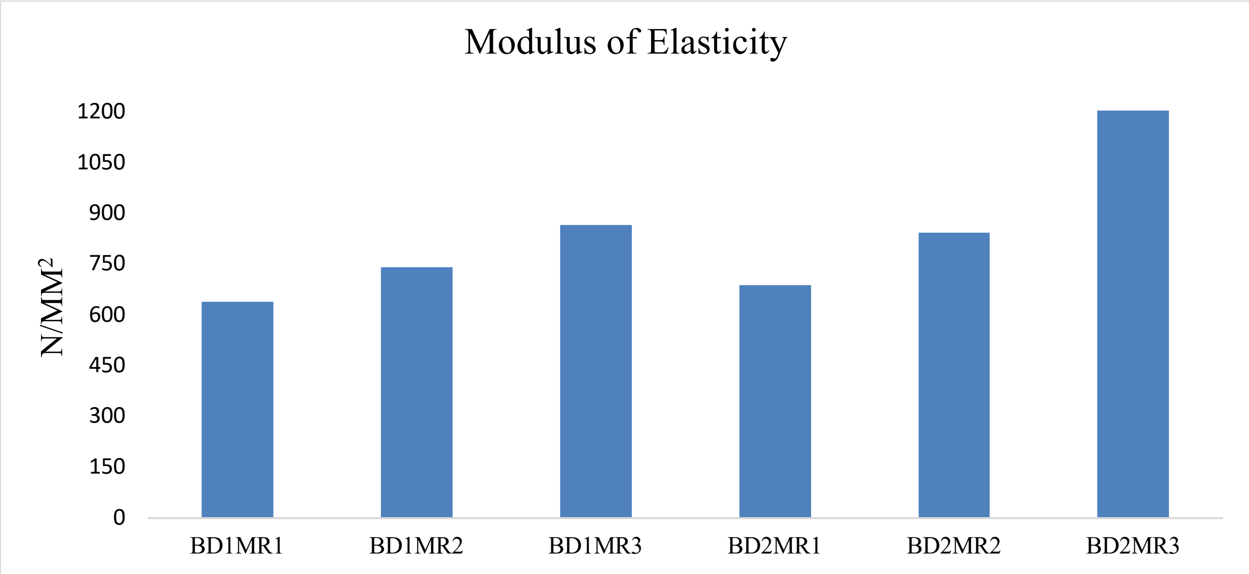

Figure 3: Effect of production variables on Modulus of Elasticity

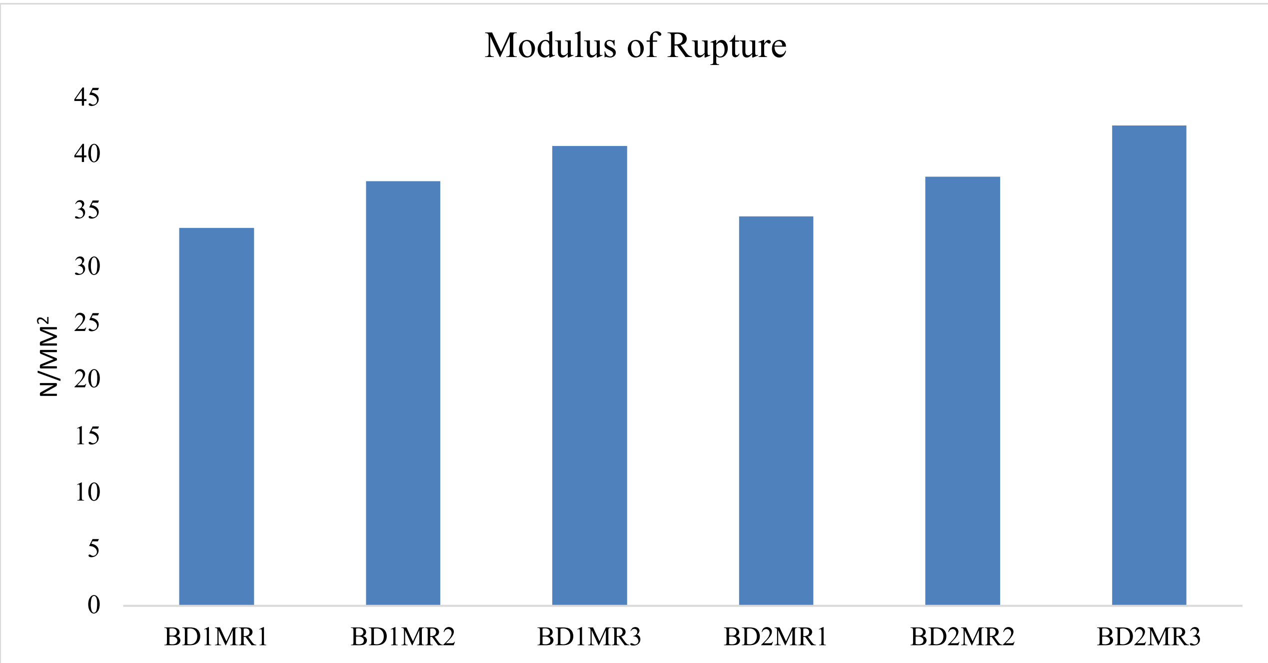

Figure 4: Effect of production variables on Modulus of Rupture

Conclusion

The result of this study has shown that the pod of *Delonix regia* and pure water sachet are suitable for the production of Wood Plastic Composites. The dimensional stability of the boards is enhanced with increased level of density and mixing ratio. A higher proportion of plastic increases the properties of the composite boards because an increase in plastic content resulted in dimensional stability while the mechanical properties of the boards were also improved.

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